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I, JULIE BILLINGSLEY, TEAM LEADER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. 2003905272 for a patent by NEC AUSTRALIA PTY LTD as filed on 26 September 2003.



WITNESS my hand this
Eighteenth day of October 2004

A handwritten signature in cursive script, appearing to read 'J. Billingsley'.

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Patents Act 1990

PROVISIONAL SPECIFICATION

Invention Title:

**Computation of soft bits for a turbo decoder in a
communication receiver.**

The invention is described in the following statement:

COMPUTATION OF SOFT BITS FOR A TURBO DECODER IN A COMMUNICATION RECEIVER

The present invention relates generally to to demodulation of a quadrature
5 amplitude modulation signal to generate soft bits for input to a channel decoder in a
communication receiver and in particular in a spread spectrum communication
receiver.

Communication systems employ forward error correction in order to correct
errors caused by noise generated in transport channels. For example, a
10 communication system typically uses a turbo code for the forward error correction.
At the transmitter side, turbo encoder introduces redundancy bits based on
information bits. The encoded bits at the output of turbo encoder are then modulated
and transmitted to the receiver. At the receiver end, the receiver demodulates the
received signal and produce received encoded bits to the turbo decoder. Turbo
15 decoder decodes the received encoded bits to recover the information bits.

To maximize the advantage of the coding gain obtained by the iterative
decoding process in the turbo decoder, rather than determining immediately whether
received encoded bits are zero or one, the communication receiver assigns each bit
of value on a multi level scale representative of the probability that the bit is 1. A
20 common scale, referred to as Log-Likelihood Ratio (LLR) probabilities, represents
each bit in an integer in some range, for example -32 to 31. The value of 31
signifies that the transmitted bit was 0 with a very high probability, and a value of -
32 signifies that the transmitted bit was 1 with a very high probability. A value of 0
indicates that the logical bit value is indeterminate.

25 The turbo decoder in a communication receiver uses the LLR to determine
whether a given information bit were transmitted given a particular received
encoded bits. However, the computation of the LLR probabilities is a time-
consuming and processing-intensive calculation. By way of explanation, in a
transmitter of a communication system, each N encoded bits are mapped to one
30 symbol (2 dimensional symbol with I and Q components). The symbol is

transmitted over a channel to reach a receiver. The received symbol is attenuated and corrupted by noise. The task of the receiver's demodulator is to recover the N encoded bits from that noisy received symbol. To utilize the coding gain of the turbo decoder, N soft bits (or LLR) are generated.

- 5 Usually, the log likelihood is used to approximate the soft bit. The log likelihood $L(b_i)$ for i-th bit ($i=0,1,...,N-1$) is calculated as:

$$L(b_i) = \ln \frac{P(b_i = 0 | y)}{P(b_i = 1 | y)} = \ln \frac{\sum_{z|b_i=0} P(z | y)}{\sum_{z|b_i=1} P(z | y)} \approx \frac{1}{2\sigma^2} (\min_{z|b_i=1} |y - z|^2 - \min_{z|b_i=0} |y - z|^2)$$

- where y is the received symbol, z is a symbol in the reference constellation, and σ^2 is noise variance. From this formula, it can be seen that significant
10 computational complexity is involved in the estimation of σ^2 , the estimation of the reference constellation (estimation of average amplitude of the desired signal), the calculation of the distances and min searches and the division to derive $L(b_i)$

- In order to simplify the log likelihood computation, a simplified method is proposed in International Patent Application No WO 01/67617 for generating the
15 soft decisions. A particular example described in that document is the demodulation of a 16 Quadrature Amplitude Modulation (QAM) signal in a spread spectrum communication system. A 16 QAM constellation is shown in Figure 1, where each of the 16 symbols in the constellation corresponds to 4 encoded bits. Figure 2 highlights the relationship between the encoded bits and the location of
20 each symbol. For example, if $b_0=1$ and $b_1=0$, the symbol has negative I and positive Q component. Based on similar observations for b_1 and b_3 , soft bits $L(b_i)$ can be generated as follows:

$$L(b_0) = yI, L(b_1) = yQ, L(b_2) = Sth - abs(yI), L(b_3) = Sth - abs(yQ)$$

- However, a complex circuit must be used in the arrangement described in the
25 above-mentioned document for calculation of Sth, which involves:

- (i) calculation of interference power and calculation of desired signal power for each multipath based on pilot signal, and

(ii) mapping signal and interference power to C/I for each path, and summing to get total C/I, which is then used as an estimate of the threshold S_{th}

Accordingly, there currently remains a need to compute log-likelihood ratios for use by a turbo decoder in a computationally simple manner.

5 It would be desirable to provide a technique for computing a threshold value used in the computation of log-likelihood metrics that minimises the time, processing resources and power requirements of a communication receiver.

It would also be desirable to provide a technique for calculating log-likelihood ratio metrics in a manner that ameliorates or overcomes one or more
10 disadvantages of known techniques.

With this in mind, one aspect of the invention provides a method for computing a threshold S_{th_i} used in demodulating a quadrature amplitude modulated (QAM) signal to generate a plurality of soft bits per received symbol for input to a turbo decoder, the method including the steps of:

- 15 (a) computing the mean amplitude A of the received symbols; and
- (b) multiplying the mean amplitude A by a normalising parameter Δ for a square QAM constellation with 4^m points, such that

$$S_{th_i} = A \times 2 \times i \times \Delta$$

20

where $m > 1$ is a positive integer and i is a positive integer from 1 to $(\sqrt{4^{m-1}}) - 1$.

A method including these steps efficiently calculates the threshold used in demodulating a QAM signal to generate a plurality of soft bits per received symbol for input to a turbo decoder in High Speed Downlink Packet Access (HSDPA)
25 applications. The threshold is computed as a product of the average amplitude of the received signal and a constant or fixed scaling factor. The estimation of average amplitude of the received signal is relatively straight forward to computed and can be performed efficiently in hardware.

In one application of the invention, the QAM signal is a 16QAM signal and
30 the threshold S_{th_i} equals $A \times 2 \times \frac{1}{\sqrt{10}}$.

Another aspect of the invention provides a method for generating soft bits per received symbol for input to a turbo decoder used in demodulating a quadrature amplitude modulated (QAM) signal, the method including the steps of:

- (a) computing the mean amplitude A of the received symbols; and
- 5 (b) multiplying the mean amplitude A by a normalising parameter Δ for a square QAM constellation with 4^m points to derive a threshold Sth_i , such that

$$Sth_i = A \times 2 \times i \times \Delta$$

where $m > 1$ is a positive integer and i is a positive integer from 1 to $(\sqrt{4^{m-1}}) - 1$; and

- 10 (c) computing one or more of the soft bits from the threshold Sth_i .

As has been explained previously, an efficient way of demodulating a QAM signal is to generate a plurality of soft bits for input to a turbo decoder usually involves calculation of a threshold. A demodulator typically produces the first two soft bits equal to an I component and Q component of a received symbol. One or
15 more of the remaining soft bits are able to be generated according to the present invention as differences between the absolute values of the I component and Q component and the threshold. The simple manner in which the threshold is derived therefore minimises the complexity of the required hardware in a communication receiver.

20 Yet another aspect of the invention provides a device for computing a threshold Sth_i used in demodulating a quadrature amplitude modulated (QAM) signal to generate a plurality of soft bits per received symbol for input to a turbo decoder, the device including:

- means for computing the mean amplitude A of the received symbols and
- 25 multiplying the mean amplitude A by a normalising parameter Δ for a square QAM constellation with 4^m points, such that

$$Sth_i = A \times 2 \times i \times \Delta$$

where $m > 1$ is a positive integer and i is a positive integer from 1 to $(\sqrt{4^{m-1}}) - 1$.

A still further aspect of the invention provides a device for generating soft
30 bits per received symbol for input to a turbo decoder used in demodulating a

quadrature amplitude modulated (QAM) signal, the device including:

means for computing the mean amplitude A of the received symbols and multiplying the mean amplitude A by a normalising parameter Δ for a square QAM constellation with 4^m points to derive a threshold Sth_i , such that

$$Sth_i = A \times 2 \times i \times \Delta$$

where $m > 1$ is a positive integer and i is a positive integer from 1 to $(\sqrt{4^{m-1}}) - 1$; and means for computing one or more of the soft bits from the threshold Sth_i .

Yet another aspect of the invention provides a communication receiver including a device as described here above.

The various features and advantages of the present invention will become more apparent from the following detailed description when taken in conjunction with the accompanying drawings, in which:

Figure 1 illustrates a diagram of a 16 QAM signal constellation mapping;

Figure 2 is a diagram of the constellation mapping showing the value of each of 4 encoded bits within a grey code representing each symbol in the constellation mapping;

Figure 3 is a schematic diagram of a communication system including a communication receiver in accordance with one embodiment of the present invention; and

Figure 4 is a schematic diagram of a soft bit estimator forming part of the communication receiver shown in Figure 3.

Referring now to Figure 3, there is shown generally a communication system including a transmitter 11 connected to a digital source 12 and configured to receive binary input data from the digital source 12. The transmitter 11 generates and transmits a modulated signal 13 for reception by a receiver 14. The receiver 14 acts to demodulate the received signal and recover decoded binary data which is then forwarded to a destination 15. The transmitter 11 includes a turbo encoder 16, signal mapping block 17 and modulator 18. The receiver includes a demodulator 19, log-likelihood estimator 20 and turbo decoder 21.

Binary input data 22 to be transmitted is encoded with a turbo code by the

turbo encoder 16, which generates a sequence of binary symbols 23 referred to as encoded bits. Several encoded bits are blocked together and mapped to a point on a signal constellation by the signal mapping block 17, thereby generating a sequence of complex-valued modulation symbols 24. This sequence is applied to the modulator 18, which generates a continuous-time wave form for transmission to the receiver 14.

The demodulator 19 demodulates the received modulated signal and generates a sequence of complex-valued soft symbol 25. Each soft symbol represents an estimate of a modulation symbol that was transmitted by the transmitter 11. These estimates are used by the log-likelihood estimator 20 to extract log-likelihood metrics (soft bits) 26 associated with the given modulation symbol. The turbo decoder 21 uses the sequence of log-likelihood metrics (soft bits) to decode the binary data that was originally transmitted and recover decoded binary data 27.

The square 16 QAM constellation shown in Figure 1 has an index $m=2$ and is defined to be a signal constellation with 4^m points. Each signal point is denoted by its index (i,j) where $0 \leq i, j < 2^m$. The position of each i,j point on the constellation is given by the following formula:

$$c_{i,j} = \{(2^m - 1 - 2i) \Delta, (2^m - 1 - 2j) \Delta\} \text{ where } \Delta = \sqrt{\frac{3}{4^m - 1} \left(\frac{1}{2}\right)}.$$

The above formula ensures that the average energy of the signal constellation is normalised to one, where Δ is a normalisation parameter for a square QAM constellation. For a 16 QAM constellation, $m=2$ and $\Delta = \frac{1}{\sqrt{10}}$. For other square QAM constellations, the value of both m and Δ will change. Accordingly, for a 64 QAM constellation, $m = 3$ and $\Delta = \frac{1}{\sqrt{42}}$, whilst for a 256 QAM constellation, $m = 4$ and $\Delta = \frac{1}{\sqrt{170}}$.

Each signal pointing the constellation is labelled with a binary string that

denotes a block of encoded bits associated with the modulation symbol. As can be seen in Figure 1, grey code mapping is used to associate the modulation symbols with blocks of encoded bits. In this case, each of the 4^m points in the constellation is identified by a 4 bit code including bits b0, b1, b2 and b3. In other square QAM constellations, the number of bits in the grey code may vary. For example, in a 64 QAM constellation, each point is identified by a 6 bit grey code.

Because information and encoded bits are random, all 16 symbols in the constellation shown in Figure 1 are expected to occur with a relatively equal probability given a sufficient observation length in the processing circuitry of the receiver 14. An optimal threshold should therefore provide an equal likelihood for the bits b2 and b3. The mathematical expectation, or mean, of likelihood values for the bits b2 and b3 should also be the same. If there is no noise in the received signal, the threshold Sth will therefore fall in the middle of b2 (or b3) = 0 and b2 (or b3) = 1 as shown in Figure 2. If the received signal is corrupted by noise, the distribution of the absolute values of the I and Q components will spread out and the threshold will be shifted to the right compared to the case in which no noise is present.

Taking this into account, an optimal value for the threshold Sth is given by the following formula:

$$Sth = \sqrt{E} \times \frac{2}{\sqrt{10}} = A \times \frac{2}{\sqrt{10}} = A \times \text{const}$$

where E and A are respectively estimates of the mean energy and amplitude of received symbols in the demodulator 19. The value of the constant is given by $\frac{2}{\sqrt{10}}$ and is calculated, according to Figures 1 and 2, so that the threshold Sth falls in the middle of b2 (or b3)=0 and b2 (or b3)=1 if there is no noise. If the received signal also contains noise, then the estimate data energy E also includes signal and noise variance and the estimated threshold is therefore larger than in the case of no noise. In this instance, the estimate can be used as an approximation of the optimal threshold.

The above described example can be generalised to cover other square QAM

constellations with 4^m points. In this generalised case, the optimum value of the threshold $Sth_i = A \times 2 \times i \times \Delta$, where m is a positive integer and i is a positive integer from 1 to $(\sqrt{4^{m-1}})-1$.

It will be appreciated that the computation of A and the multiplication of A by a constant to derive the optimal value of the threshold Sth_i is very simple and efficient to implement in hardware. One such hardware implementation is illustrated in Figure 4, which shows a more detailed view of the log-likelihood estimator 20 of the receiver 14. In this Figure, the channel estimates yI_k and yQ_k are received from the demodulator 19. The average amplitude of the I channel estimate over K symbols is determined by a first averaging block 28. Similarly, the average amplitude of the Q channel estimates over K symbols is computed in the second averaging block 29.

The outputs of the averaging blocks 28 and 29 are input into a processing block 30 which approximates the mean amplitude A of each received symbol according to the equation $A \approx \max(AI, AQ) + 0.5 \min(AI, AQ)$. The processing block 30 multiplies that mean amplitude A by a constant which in the case of a 16 QAM signal $= \frac{2}{\sqrt{10}}$ to determine an optimised value of the threshold Sth .

The calculated threshold value is then applied at the output of the processing block 30 to the inputs of subtraction blocks 31 and 32. In subtraction block 31, the absolute value of the I channel estimate for each symbol is subtracted from the threshold value Sth to derive the log-likelihood of the bit b_2 . Similarly, the absolute magnitude of the Q channel estimate for a received symbol is subtracted from the value of the threshold Sth to derive the value of the log-likelihood of the bit b_3 . The log-likelihoods of the bits b_0 and b_1 respectively equal the received I and Q channel estimates.

Accordingly, the log-likelihood estimator 20 provides 4 log-likelihood outputs $L_k(b_0), L_k(b_1), L_k(b_2), L_k(b_3)$ corresponding to each of 4 soft bits provided to the turbo decoder in use in demodulating the 16 QAM signal. In this figure, the log-likelihood estimator 20 approximates the amplitude A and the threshold Sth based

on K input symbols, and then uses this approximated value for demodulating each of those K received symbols.

It will be appreciated that in other embodiments of the invention involving square QAM constellations other than the 16 QAM constellation described above, the same principle is used by the log-likelihood estimator²⁰ the threshold Sth however the processing block 30 may be required to calculate multiple threshold values $Sth_i = A \times 2 \times i \times \Delta$, where $m > 1$ is a positive integer and i is a positive integer from 1 to $(\sqrt{4^{m-1}}) - 1$. For example, in the case of a 64 QAM signal constellation, the thresholds $Sth_{(1/2/3)}$ will be equal to $A \times \frac{(2/4/6)}{\sqrt{42}}$. Similarly, for a 256 QAM signal constellation, the thresholds $Sth_{(1/2/3/4/5/6/7)}$ equals $A \times \frac{(2/4/6/8/10/12/14)}{\sqrt{170}}$.

By taking advantage of the randomness of data transmitted, the computation of the log-likelihood values is independent from the symbol processing, and can be realised as a stand alone block. Moreover, no assumptions about data to pilot ratio or proportional of pilot signal over total power need be made. The processing required to effect this computation is very simple and efficient, and requires minimal power consumption and time.

Finally, it is to be understood that various modifications and/or additions may be made to the above described method or device without departing from the spirit or ambit of the invention.

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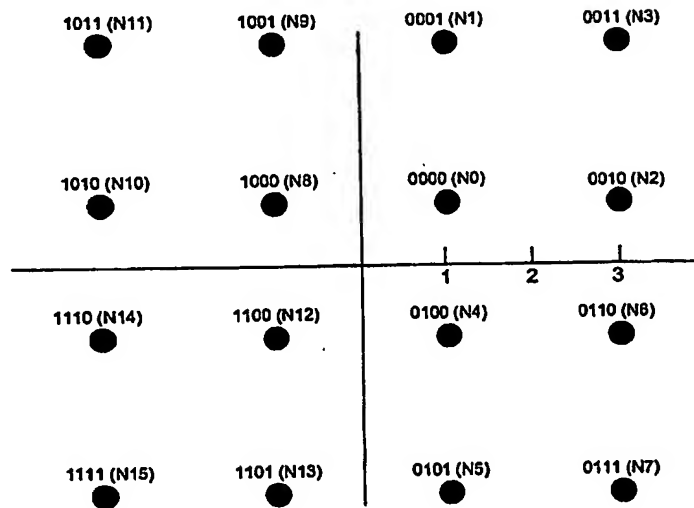


Figure 1

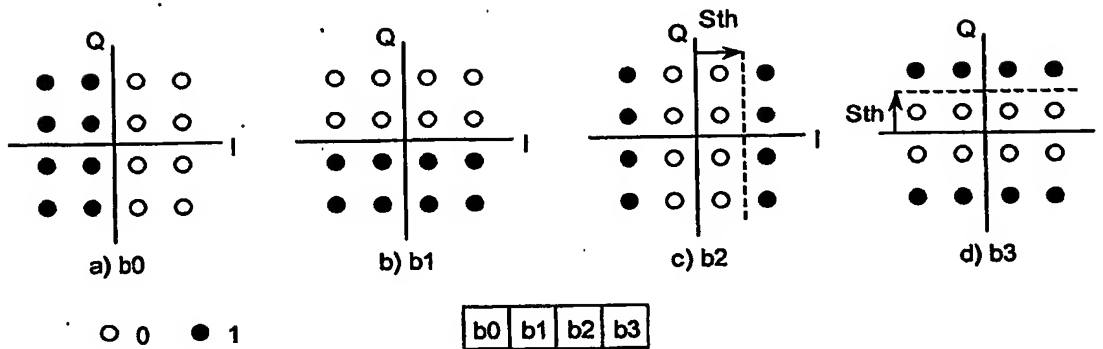


Figure 2

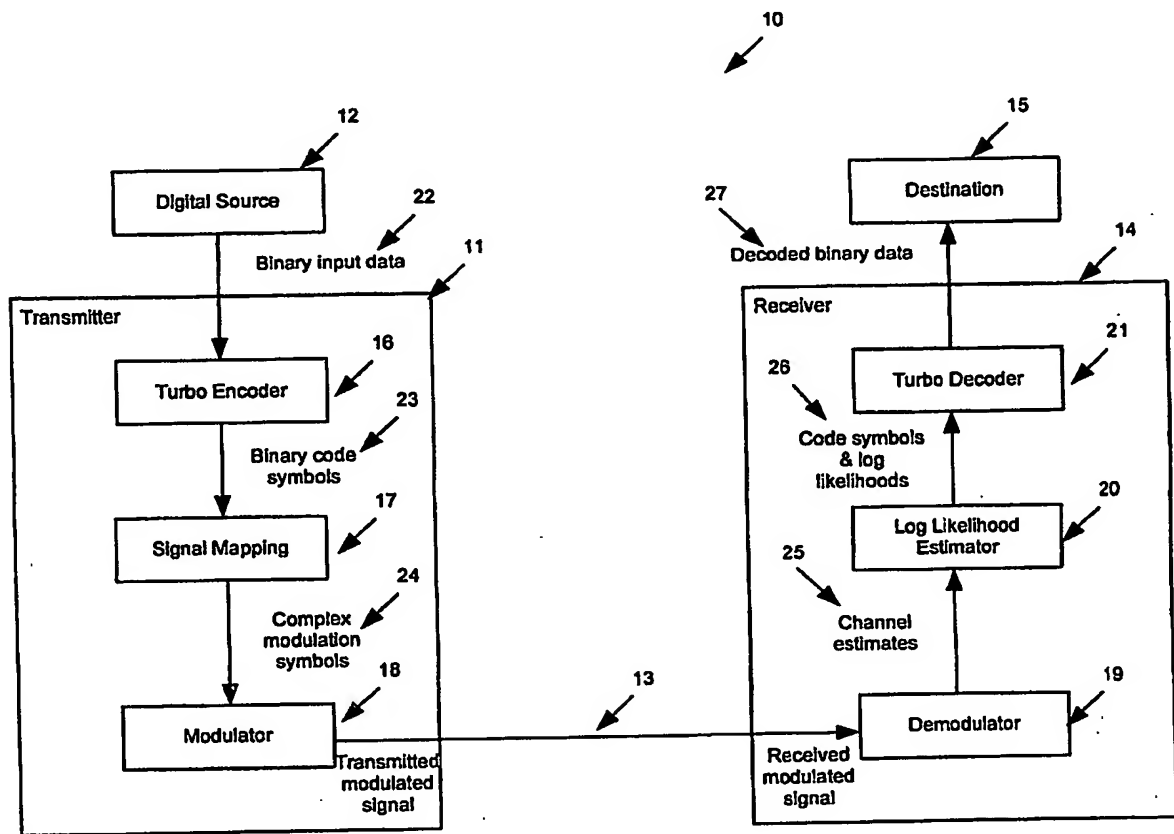
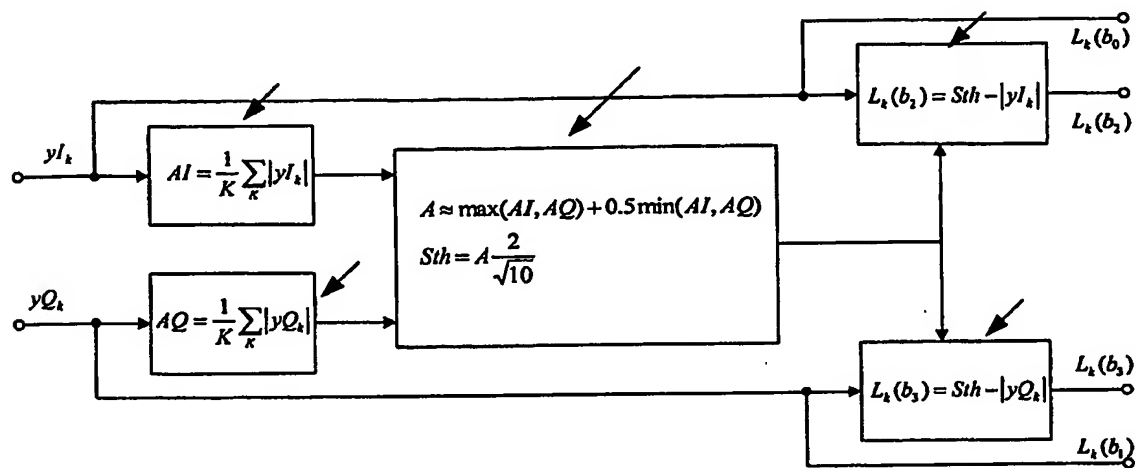


Figure 3



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